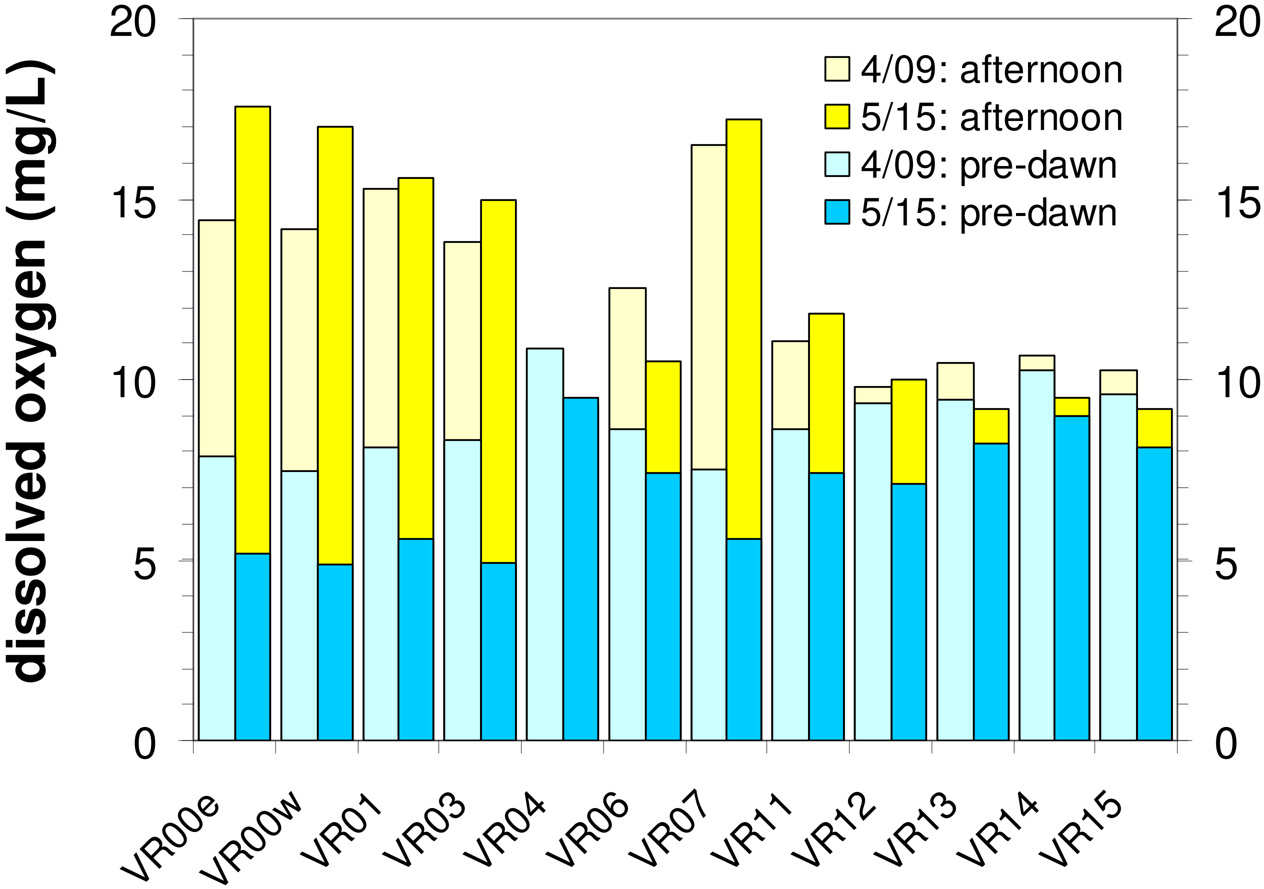
Al Leydecker: May 30, 2008



On May 15, 2008, Santa Barbara Channelkeeper measured diel variations in dissolved oxygen (DO) and *p*H at 11 locations on the Ventura River. Measurements were made either in the stream itself or from samples collected by bucket tossed from a bridge into the center of flow (bucket samples allow faster and easier measurement, especially at night). Pre-dawn measurements were made from 4:40 to 5:45 AM, afternoon measurements between 2:05 and 3:30 PM. The dissolved oxygen values recorded, along with differences between the two readings, are shown on the graph (in mg/L, i.e., ppm). They are shown with results from a similar sampling a month earlier (April 9) to illustrate change as the algal season progressed. Site numbers indicate the regular Channelkeeper monitoring locations at which measurements were made; VR00 indicates samples collected along the east (e) and west (w) sides of the railroad causeway over the Ventura estuary (Figure 3).

Algal growth produces a daily cycle in both DO and *p*H: daylight photosynthesis adds oxygen while removing carbon dioxide; nighttime respiration reverses the process. DO concentrations in the surrounding water typically peak around mid-afternoon and decline to a minimum just before sunrise. The magnitude of the change in DO reflects both the abundance of algae, the extent of their biological productivity, i.e., how hard they are working, and the amount of water in which this change in DO is reflected. A fixed amount of algae will produce increasingly greater changes in DO as the volume (or flow) of water decreases. And since the dominant alga at all these sites is still cladophora, which usually grows outward from a rock substrate, water depth is also a factor: the shallower the flow, the easier it is for algae to change its characteristics.

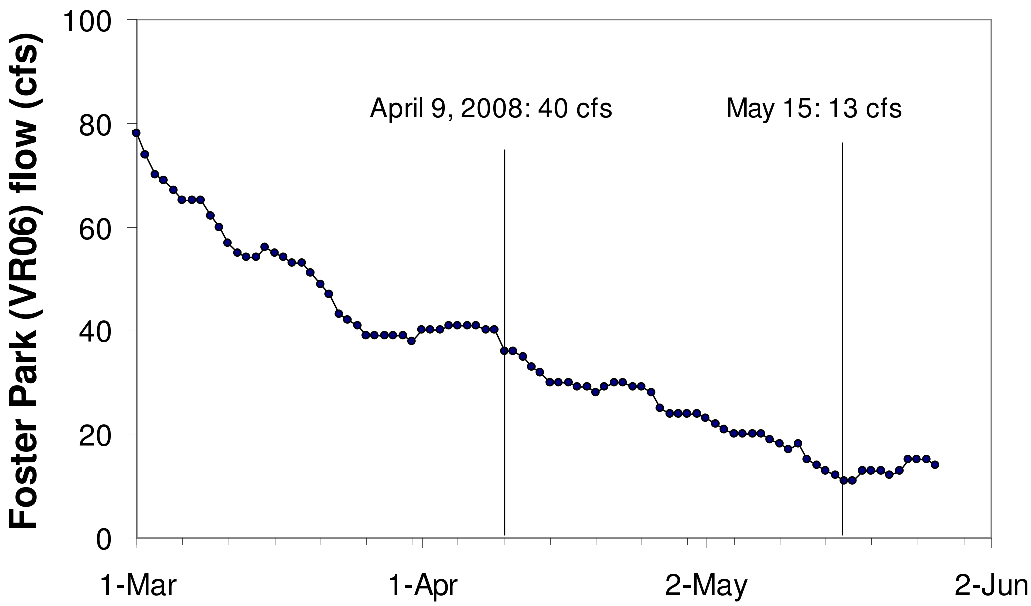
Figure 1. VR01, Main Street, looking upstream: April 9, 2008 on top, May 15 on bottom. Aside from greater amounts of released (free floating) cladophora anchoring on rocks, conditions are relatively unchanged.

Figure 2. VR06, Foster Park, looking downstream: April 9, 2008 on top, May 15 on bottom. The first bloom has ended and algal decay is far along.

Figure 3. VR00, Ventura Lagoon on May 15, the murky green color (from phytoplankton) noticed on April 9, 2008 is gone, replaced by macro algae growing up from and on the bottom. The water is completely fresh.

The location with the greatest diel variation was the Ventura Lagoon (VR00; from ~5 to 17 mg/L, from 50-60 % saturation to over 200), but all sites below the Ojai Treatment Plant had appreciable day-night DO differences as did lower San Antonio Creek. Unlike in April, when phytoplankton (micro-algae suspended in the water column) appeared to be the major cause of DO fluctuations in the lagoon, macro-algae, growing up from the bottom, and on the bottom itself, seemed to dominate (Figure 3; in contrast with the soupy green color of April, lagoon waters were generally clear and un-turbid). Interestingly, lagoon water was completely fresh; it's conductivity, 1095 µS/cm, was about the same as that usually measured at Main Street (1089 µS/cm on May 1, 1129 on May 23).

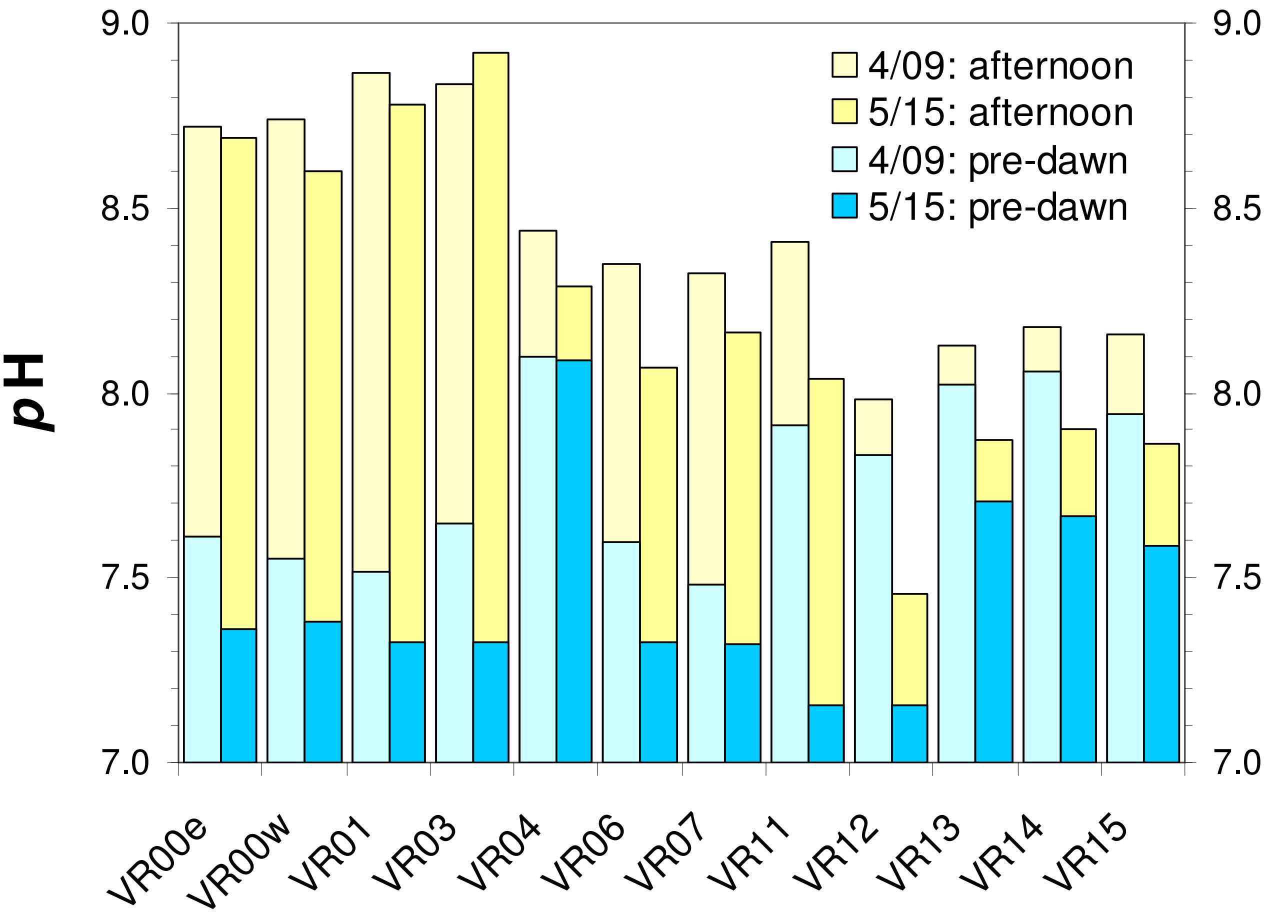
Above the lagoon, sites could be roughly divided into two categories: those that showed a more exaggerated DO cycle in May than a month earlier (higher mid-afternoon and lower pre-dawn concentrations; VR01-04, VR07, VR11 and VR12), and those exhibiting a May cycle featuring *both* lower mid-afternoon and lower pre-dawn concentrations (VR06, VR13-15). A more pronounced DO cycle can be caused by greater algal growth (increased photosynthesis) or lower streamflows (a reduced volume of water magnifies algal impact) or both. As discussed in the last report, shallower or slower flows, which can be a characteristic of lower overall streamflow, also enhance algal impacts.



As the above graph shows, average daily flow on May 15 at Foster Park was only a third of what it had been during the previous April sampling. If we take this as indicative of conditions elsewhere in the watershed (Ventura County data, which are usually not very accurate, show a mixed picture: N.F. Matilija down 50%, flow above Matilija Dam down 80%, Matilija Creek down only slightly) there was substantially less water on May 15 so even algal growth past the peak of its bloom (i.e., lower overall photosynthetic output) should have been able to appreciably increase the magnitude of the diel cycle. Which makes lowered mid-afternoon DO readings at a large number of sites noteworthy. However, a look at photos contrasting the mid-May appearance of these locations with that of early April indicates the probable cause.

Figure 4. VR13, Matilija Creek, below the dam, on April 9 above, May 15 below. Algae at all the Matilija sites had gone into decline during the intervening period.

Advanced decay of the algal bloom at VR06 (Foster Park, Figure 2), VR13 (Figure 4), VR15 (Figure 5) and VR14 (Figure 6) is the undoubted reason. As algae decay within an oxygenated water column the dominant process is aerobic – the oxidation of organic matter producing carbon dioxide. This utilization of water column oxygen should produce lower pre-dawn DO levels and, indeed, we see this at all the effected sites. Decay will also reduce mid-afternoon levels, but these readings will be somewhat offset by photosynthesis from whatever still functioning algae remain. Often times decaying cladophora will be colonized by diatoms, but a film of these, also photosynthesizing, organisms never has the impact of macro-algae at the height of its bloom. I should point out that a number of locations showing pronounced decay and reduced mid-afternoon concentrations actually had enhanced DO cycles; the lower daytime readings more than offset by even lower pre-dawn oxygen concentrations, evidence that appreciable photosynthesis was still taking place. One way to think about these locations is that lower flows, combined with decreasing but still ongoing photosynthesis, managed to produce a stronger diel cycle, but one depressed by aerobic decay. Only VR06 and VR13 had more reduced cycles in May than in April.

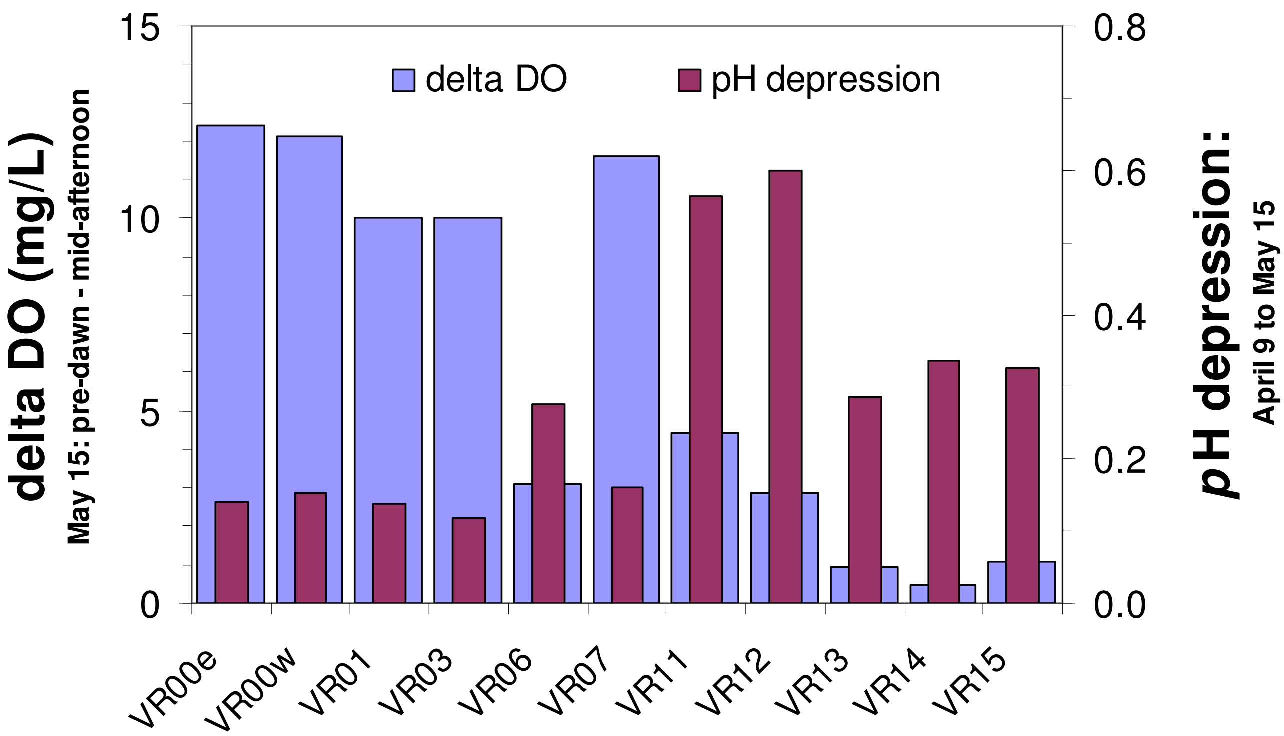


Carbon dioxide in water forms a mild acid (carbonic acid) and as it is removed by photosynthesis water becomes increasingly basic, i.e., the *p*H increases. This is similar to a soft drink or beer tasting flat after it sits awhile and looses carbonation; loss of carbonation equals loss of acidity.

Figure 5. VR15, Matilija Creek, above the dam, on April 9 above, May 15 below. The cladophora has past its peak and is mostly in decay.

So the diel *p*H cycle follows that of DO: *p*H, in the presence of algae, rises to an afternoon peak and then declines to a pre-dawn minimum. At locations exhibiting an stronger DO cycle in May than they showed in April we would expect the *p*H cycle to be similarly enhanced. And it was.

As with DO, most sites had a stronger *p*H cycle in May, even VR13 with a reduced DO fluctuation. The exceptions being VR06 and VR07 where the May *p*H cycle was the same as in April, and VR04 where it was lower. However, only at Shell Road (VR03) the closest site below the Ojai Sewage Treatment Plant, was mid-afternoon *p*H higher in May than it had been in April (8.92, the highest value measured on May 15; the diel *p*H cycle at VR03 was 1.6 *p*H units). Discounting the possibility of error, a working hypothesis would be that decay of the cladophora bloom is ongoing everywhere on the Ventura; it's not a matter of decay at some locations and not at others, but, rather, how far decay has advanced at some sites in contrast with others. Decay introduces greater amounts of carbon dioxide into the stream depressing both pre-dawn and mid-afternoon pH values, more advanced decay simply occasions greater *p*H depression.



The above chart shows the magnitude of the diel DO variation at each site (VR04 was excluded since mid-afternoon DO was exceeded by the pre-dawn concentration due to extreme temperature variation – see first report) on May 15 (delta DO) and the difference between average *p*H on May 15 from that on April 9, i.e., the amount average *p*H values decreased between the two dates (*p*H depression). Greater depressed pH at sites with reduced DO cycles, and lower depression at those with appreciable diel DO variations, provide evidence for the hypothesis. Only VR11 and 12 would seem to offer contrary results. At these sites, where flow has been drastically reduced (both are about to go dry),

Figure 6. VR14, North Fork Matilija Creek, April 9 on the right hand side, May 15 on the left. Again, cladophora has past its peak – the vibrant green color is gone – and is decaying. (No, I was not exhibiting an artistic flourish in April, the shutter, unbeknownst to me, failed to fully open.)

algal decay is greatly advanced (pre-dawn *p*H at both sites was 7.15 – extraordinarily low values for the Ventura), but trickling flows and some lingering photosynthetic algae are still providing an appreciable DO cycle (more so at VR11 than at VR12; mid-afternoon *p*H and DO at the former were 8.41 and 11.85 mg/L vs. 7.98 and 9.98 at the latter).

Large variations in *p*H are considered dangerous, a change of more than two points on the *p*H scale can kill many species of fish. The EPA and the LA Regional Water Quality Control Board regard a *p*H change of more than 0.5 as harmful and 6 of the sites had pH variations greater than this in May (and the same 6 in April; all sites below VR12 with the exception of VR04). A half a unit of *p*H is not a small thing, the scale is logarithmic and half a unit represents a 500 percent change. In April, on the lower river (VR11-VR01) a 1 unit change in *p*H was roughly accompanied by a DO increase of 5 mg/L. The May ratio was slightly greater, but similar: 1 pH unit for every 6 mg/L DO increase. In the last report I attributed this relationship to the amount of buffering in the stream – and it could well be true if the modest May increase was caused by increased buffering (i.e., increased ANC or *acid neutralizing capacity*) due to increased evapo-concentration (lower flows and higher water temperatures leading to an increased concentrations of solutes). If so, that the sensitivity within the lagoon increased from ~6 mg/L of DO for every unit of pH change in April to nearly 10 mg/L in May is intriguing. Absent ANC measurements on both river and lagoon there can be no resolution of this puzzle at this time.

Having explained *what* was happening at each location (at least to my own satisfaction), however, does not explain *why* it happened. As the season moves on I've become increasingly convinced that nutrients do play an important role. Not so much reach nutrient concentrations per se, but as a component of the flux provided to growing algae – flux being the product of concentration multiplied by flow. Relatively low concentrations in high-flow environments (e.g., riffles or runs) can maintain healthy growth, while adjacent slow-flow areas (e.g., pools) are decaying rapidly. The stream micro-environment becomes all important. Thick growth in slow-flowing sections may become self-limiting as the inner-most algae become nutrient starved and die – allowing entire clumps to float free and form mats against boulders and in slack-water areas (visible in Figures 1, 2 and 8).

High nutrient environments have higher fluxes – in both riffles and pools – and algae can grow denser and last longer. Self-limiting and sloughing, while still problems, are not as critical and occur only after greater densities of algal growth accumulate. In both high and low nutrient environments, faster stream velocities usually mean denser and longer lasting blooms, the difference provided by increased nutrient concentrations being the ultimate size of the bloom and how long it lasts. (I use the term "usually" since higher velocities may also delay the establishment of benthic algae.) It's not simply a question of algae or no algae, but of how much algae. Algae also lasts longer and grows thicker in high velocity micro-environments – for example, on top of submerged rocks and at the sides of boulders.

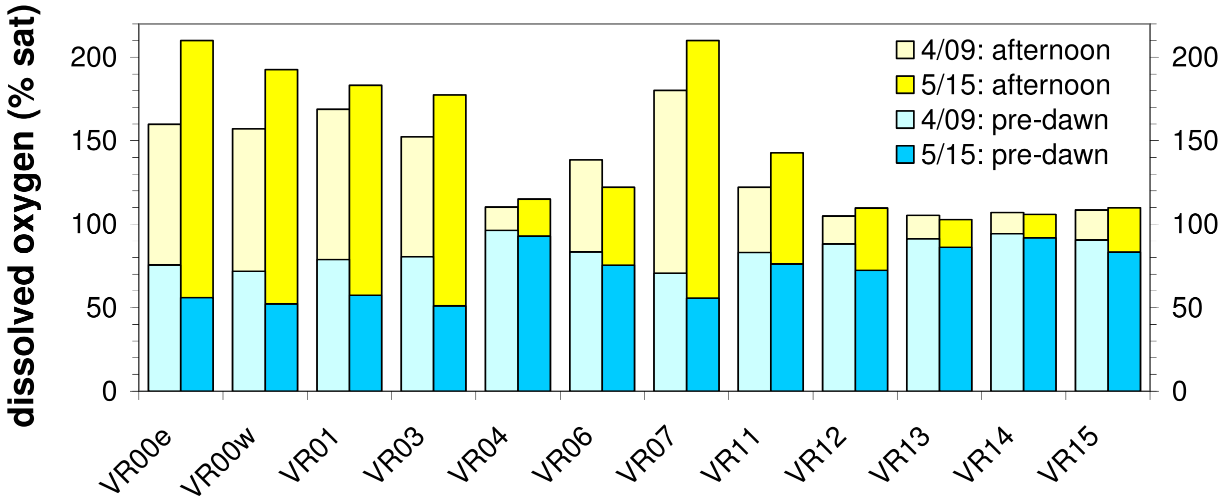
Figure 8 illustrates some of these kinds of changes as seen by Kristi and myself (we are currently doing algal surveys as part of a UCSB research project sponsored by the LA Regional Board) as we moved downstream during May 17-20. Locations above the Ojai Treatment Plant can be considered low nutrient environments. Although nutrient concentrations from samples taken this season are as yet unavailable, dry-season concentrations at Foster Park are typically circa 30 µM (0.42 mg-N/L) or less for nitrate and twice that for total dissolved nitrogen (TDN).

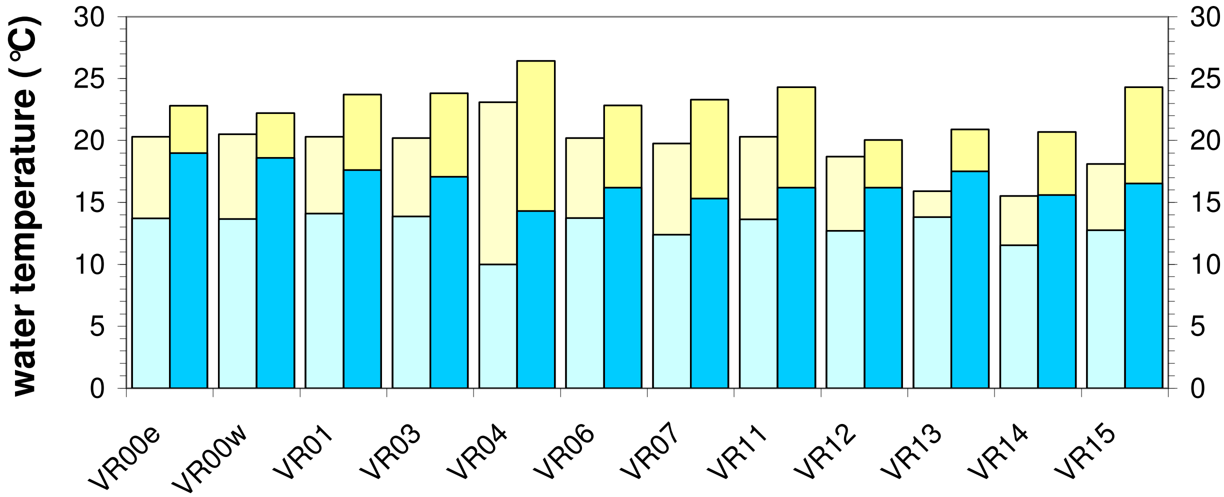
Figure 8. (a) dense algae in a run above the San Antonio confluence; (b) dense algae in a riffle below the confluence; (c) decaying algae in an adjacent pool; (d) algae in advanced decay in a pool further down (above the treatment plant); (e) dense, vibrant algae below the treatment plant; (f) but even here algae in an adjacent pool is in decay. Reaches shown in (a), (b), (c) and (d) can be considered "low" nutrient.

Concentrations usually decrease from April or May on, dropping to roughly half by early fall. Figure 8 shows a progression from dense algal growth – in spite of low concentrations – in a reach of fast flowing riffles and runs above the San Antonio confluence (a) to similar growth in a riffle below the confluence (b), contrasted with decaying cladophora in pools just below that riffle (c). (Lower San Antonio Creek generally has dry-season nutrient concentrations below those of Foster Park and was adding negligible amounts of flow at this time.) Dropping below Foster Park to just above the treatment plant outfall, (d) shows pool algae in advanced stages of decay. Immediately below the treatment plant algae (e) is again both vibrant and luxurious, indeed, the densest algal growth we saw during that week on the river, but even in this reach algae in pools adjacent to runs and riffles was beginning to decay (f). Nutrient concentrations below the treatment plant vary considerably, dependent on the amount of Foster Park flow available to dilute high effluent concentrations, but the long term average at VR03 is 1.91 mg-N/L for nitrate, 2.32 mg-N/L for TDN – a high nutrient environment by any definition of the term. Unlike reaches above, where concentrations decrease as the summer progresses, immediately below the plant concentrations increase as Foster Park flows diminish.

The dramatic algal differences seen in the watershed during and after May 15 can be explained by the interaction of nutrient fluxes in the various reaches with the standing algal crop. Where the flux is high (riffles and runs in reaches with moderate or high nutrient concentrations) algae are still flourishing, but decay is well on its way in stagnant areas and pools in these same sections. Although all sections of the river below the plant still have abundant algae, there appears to be a definite decrease in growth and health as you move downstream (there has been a reversal in the relative intensity of the diel pH and DO cycles at VR01 and VR03 between the two samplings: in April, VR01 had the greater variation, in May, VR03). Since nutrient concentrations show a similar pattern of decline it's hard to avoid assuming a relationship between the two.

Elsewhere, in low nutrient environments such as the Matilija reaches and lower San Antonio, low nutrient fluxes combined with the self-limiting characteristics of dense algal growth appear to have led to an early end to the bloom and rapidly progressing decay. Typically, at the Matilija locations, dry-season nitrate concentrations are near zero and TDN decreases from a high of ~0.4 mg-N/L from late March/early May to half that by the beginning of June. A similar decrease in available nitrogen this year, combined with lower flows and stream velocities, may have facilitated the early algal demise.





The earlier DO graph showed concentrations in units of mg/L. Here percent saturation, the amount of dissolved oxygen in the water compared with that expected under equilibrium conditions at the same temperature and altitude, is shown along with pre-dawn and afternoon temperatures to illustrate a few points. First, that water temperatures have appreciably increased at all locations. Average temperatures on the Ventura River have risen between 3-4 °C since April 9, although day/night differences have remained about the same: ~6° C. (Day/night differences are greater, circa 8 °C, at sites with appreciably lower May flows, i.e., VR07 and VR11, and greatest of all at VR04 where flow has slowed to a trickle. Interestingly, the extremely low mid-afternoon temperature at VR12 – the lowest measured that day – appears to be caused by almost total coverage at the site by a dense algal mat – insulating whatever water is still flowing from the sun.)

The temperature increase at Foster Park (VR06) is somewhat less, 2.6 °C, because colder groundwater inflows make up a majority of the flow through this location. Surprisingly, the greatest water temperature increases since April 9 (4-5 °C) were at the Matilija sites, which would seem to indicate a substantial decrease in flow. This is especially true at VR15 (a 5.1 °C increase), and lowered water levels are clearly visible in Figure 5 (lower levels are also visible at the other Matilija locations in Figures 4 and 6).

Figure 7. VR00, the lagoon, note the rise in water level from April 9 (top) to May 15 (bottom right). The sand bar is now a solid barrier (bottom left).

Day/night temperature differences in the lagoon have substantially decreased from ~7 °C in April to less than 4 °C in May. This, contrasted with a 6 °C overnight change just upstream at Main Street, indicates rising water levels in the estuary, visible in Figure 7. The figure also shows that the sand berm at the lagoon mouth now completely blocks ocean inflows (explaining the freshwater conductivity noted earlier – unfortunately lagoon conductivity was not measured in April)

Because of rising water temperatures, percent saturation is a poor measure for comparing dissolved oxygen levels from one dry-season point in time to another. The equilibrium oxygen content of water decreases appreciably as temperatures increase: 100% saturation at 23 °C, the average mid-afternoon water temperature measured on May 15, would represent a concentration of 8.27 mg/L; at 19 °C, the April 9 average, 8.95 mg/L. Comparing percent saturation on days with substantial temperature differences is a little like comparing apples with oranges; these differences can be seen by contrasting this figure with the earlier figure expressed in mg/L.

The Basin Plan covering the Ventura River calls for a minimum mean dissolved oxygen concentration of 7 mg/L, although single measurements can go as low as 5 mg/L. Pre-dawn concentrations below this minimum were found at VR00w (4.88) and VR03 (4.93). While in violation of the Plan, these concentrations are still above 4 mg/L, the point below which serious problems with oxygen deficiency could be expected to occur.

Unfortunately, these two locations still have relatively healthy standing crops of algae and as the season continues and flows further decrease their diel cycles can be expected to intensify. As discussed earlier, algal decay can also depress pre-dawn oxygen levels and sites with large amounts of decaying algae may also be continuing problem areas. 2003 saw a second cladophora bloom towards the end of August at locations not dominated by aquatic plants. Should that happen this season, given the expectation of greatly decreased end-of-summer flows in this low-rainfall year, conditions on the lower river are likely to be far worse than we have heretofore seen. It remains an open question as to whether or not aquatic plants will dominate the open wetted areas below the treatment plant as they did in 2003 (my estimate is that they will not, because the much greater flood flows of this past winter opened significantly greater sections of the channel). On the Matilija branches we can anticipate the replacement of the currently decaying cladophora bloom by increasing amounts of spirogyra – as happened last year. So these locations also bear watching as the dry-season continues.

Photos taken on May 15 (May 20 on the Matilija) can be downloaded at:

http://sbc.lternet.edu/~leydecke/Al's_stuff/Recent%20Stream-Team%20Photos/

Photos of the UCSB algal survey at:

http://sbc.lternet.edu/~leydecke/Al's_stuff/Ventura%20Nutrient%20TMDL/TMDL%20algal%20survey%20photos/